PROJECTION DISPLAY SYSTEM USING POLARIZED LIGHT

BACKGROUND OF THE INVENTION

This invention relates to projection display
5   systems which use reflective spatial light modulators,
and specifically, to such systems which incorporate
reflective liquid crystal devices, as well as to
projection display systems which incorporate polarization
converters.

10   1.   Projection Display Systems

The system shown in FIG. 1 illustrates the
essential components of the optical portion of a
projection display system having three reflective spatial
light modulators in the form of liquid crystal display
15   (LCD) panels, also referred to as liquid crystal light
valves (LCLV). The prior art system, depicted generally
at 10 includes a light source 12, an illumination
mechanism for collecting the light and concentrating it
onto the light valves, shown generally at 14, a
20   polarizing mechanism for polarizing the light, if the
light valves modulate via polarization effects, shown
generally at 16, a splitting mechanism for splitting the
illumination into three color bands to separately
illuminate the three light valves, shown generally at 18,
25   a recombining mechanism for recombining the three light
distributions after reflecting from the light valves,
shown generally at 20, and a projection mechanism for
projecting the combined images onto a viewing screen,
shown generally at 22.

30   Lamp 24 and lamp reflector 26 produce and
concentrate the light for this system. A series of
dichroic filters 28, 30 is used to split the light from
the lamp 24 into separate red, green, and blue
components. The light in each of the three components,
35   or channels, is then polarized with a polarizing beam
splitter (PBS) 32, 34, 36, and illuminates three separate
LCDs, 38, 40, 42. The LCDs selectively modify the

polarization of the light reflected from them allowing some portion of the light to pass back through the PBS. A second series of dichroic filters, 44, 46, is used to recombine the modulated light distributions and pass them

5   on to a projection lens 48 imaging all three LCDs onto the viewing screen.

The configuration shown in FIG. 1 is functional and has been used to implement projection display system products. However, the large number of components in

10   this architecture is cumbersome, and necessitates a relatively large physical size of the system. The most serious drawback to these systems is the requirement of a large back working distance for the projection lens.

A single filter, or PBS plate, tilted at 45

15   degrees requires an optical path length equal to or greater than the active width of the LCD panel. It may be seen in FIG. 1 that two of the three channels, green and red, require a PBS and two dichroic filters. These channels require a minimum optical path length between

20   the LCD and the projection lens of three times the active width of the LCD. The blue channel in FIG. 1 requires only one PBS and a single dichroic filter, but the path length must be equal to the other two channels for in-focus registration of all three images on the viewing

25   screen. The actual optical path length for the projection lens must also account for the divergence of the light after reflecting off the LCD panel. This is a function of how fast the optical system is running, usually specified by the f/# of the optical system. The

30   minimum distance referred to here is strictly valid only for systems of very high f/# and thus impractical due to low light throughput. However, for comparison with other systems this minimum figure is a good baseline. The only advantages of this architecture are the ability to

35   optimize the color filtering with the interaction of multiple dichroic structures and the ability to optimize

the PBS performance for the narrow band color channels. However, these advantages are relatively minor.

The most straightforward method of simplifying the projector architecture is to have the filter and beam splitter structures perform more than one function in the set of required system operations. System configuration 50, shown in FIG. 2, incorporates two of these simplifications. The first is the use of a single PBS 52 immediately after lamp 24, replacing the three PBS plates of the FIG. 1 system configuration. Single PBS 52 polarizes the broadband output of the lamp prior to the color splitting operation and thus functions as the amplitude modulation control mechanism for all three LCDs. This requires that the PBS function over the entire visible spectrum. The second simplification is to utilize the same set of dichroics to split the light into the three color channels and to recombine the reflected light prior to the projection optic. This requires that the dichroic filter passbands be carefully controlled since there are now only two filters 54, 56, to control the whole system colorimetry. The savings in system complexity is readily evident.

One system difficulty not addressed by the configuration in FIG. 2 is the reduction in the back working distance of the projection lens. The projection lens must still work over a distance that is a minimum of three times the active width of the LCD. A solution to this problem is found by recognizing that the operation of the dichroic filters is still the same even if the dichroic structures are crossed as shown in system 60 in FIG. 3A. This allows the back working distance to be reduced by 33% over the systems of FIGS. 1 or 2, to a minimum of twice the active width of the LCD. Unfortunately, crossing plate dichroics 62, 64, introduces a problem because the operation at the intersection of the two plates is usually disrupted by the thickness of the plates, producing a seam in the

middle of the image, where the images of the three LCD
panels are totally or partially obscured by the plate
intersection. Also, the transmission/reflection
characteristics of dichroic filters are significantly

5   different for p- and s-polarizations, which results in
the color characteristics of the whole projector being
difficult to control. This limitation is present in
FIGS. 2, 3A and 3B.

The preceding problem is solved in system 70 of

10   FIG. 3B by the introduction of a four piece color cube
filter, shown generally at 72. Dichroic filters 74, 76
are deposited on the surfaces of the four cube segments
and the pieces are then glued together to form a solid
cube with the dichroics sealed in the interior across the

15   cube diagonals. If properly assembled this arrangement
eliminates most of the obstruction of the central
crossover of the two dichroic layers. However, this
assembly is precise and the color cube component is
expensive because of the difficulty in assembly. FIG. 3B

20   also shows the use of a polarizing beam splitter cube 78.
This component is a common assembly for optical systems
and is not an expensive addition due to the significantly
less stringent assembly requirements.

As indicated in these system configurations,

25   the state-of-the-art in system architectures for
reflective LCDs includes several arrangements, each with
particular advantages and disadvantages. A desired
alternative is a system that has the small back working
distance advantages of the systems shown in FIGS. 3A and

30   3B, without the costly addition of a precisely assembled
crossed dichroic filter cube.

Jacobson et al., U.S. Patent No. 4,127,322, is
fashioned around the optically addressed Hughes liquid
crystal light valve (LCLV). A lamp output is polarized

35   by a beam splitter and then divided into the three color
paths by dichroic filters. This configuration is
equivalent to the system in FIG. 2 of the prior art. The

reference also includes an alternative embodiment in which an additional set of dichroic filters and three light valves are arranged to use the light normally discarded by the polarizer. This attempt to recover the unused portion of the light is intended to improve system throughput.

Koda et al., U.S. Patent No. 4,650,286, and Ledebuhr et al., U.S. Patent No. 4,836,649, describe architectures for the reflective LCLVs that are essentially equivalent to the system of FIG. 1, with the exception that they use a separate projection lens for each of the three light valves.

Takanashi et al., U.S. Patent No. 5,239,322, is another system designed originally for the optically addressed LCLV type light modulators. The system covered in this patent is easily recognized as equivalent to the prior art architecture of FIG. 3B. In this system the LCLVs are illuminated with images indicated as write light distributions. CRTs are typically used to produce these write light distributions and are usually abutted directly to the corresponding light modulator.

Ooi et al., U.S. Patent No. 5,648,860, uses two dichroic plates to separate the light into the three color channels and to recombine the light reflected from the LCDs. The angles of the plates used in this configuration are not 45 degrees and are set to try to reduce the back working distance for the projection optics. One of the primary purposes of Ooi et al. appears to be the use of positive lens elements directly in contact with the LCD panels to collimate the incoming illumination and to converge the reflected light, and the use of "cone-like" prisms to affect the matched convergence of the illuminating light. In all other aspects this system is essentially the same as that of FIG. 2.

Dove, U.S. Patent No. 5,658,060, is a system having a set of external dichroic filters that separate

the light into the three color paths. The light in each
path is separately polarized before illuminating the
light valves. The reflected light is recombined through
a special prism arrangement, usually referred to as a
5   Philips prism. The Philips prism is used to try to
reduce the back working distance requirements of the
projection lens. Although this system uses a prism for
recombination, it is architecturally equivalent to the
system in FIG. 1. The reference also describes another
10   embodiment that uses a cube beam splitter for recombining
the light output but continues to use separate dichroics
to affect the initial split of the light into three color
paths and to use separate PBSs for each light valve.

          Doany et al., U.S. Patent No. 5,621,486,
15   describe a simple configuration for a three-panel
projector. The system uses a Philips type prism to split
the illuminating light and to recombine the reflections
from the three LCDs. However, this setup uses a single
cube polarizing beam splitter in front of the color
20   splitting prism. This system is thus equivalent to the
architecture of FIG. 3.

          Sampsell, U.S. Patent No. 5,233,385, and
Poradish et al., U.S. Patent No. 5,612,753, describe
projection systems designed for the TI digital micro-
25   mirror device (DMD) light modulator. These references
include system architectures for both single panel color
field sequential systems and multiple panel systems. In
the multiple panel systems a color splitting prism of the
Philips type is used to perform the color separation and
30   recombination and a total internal reflecting (TIR) prism
is used to get light on and off of the DMDs. In this
case the system looks essentially the same as that of
FIG. 3b with a TIR prism used in place of the PBS cube.

          References describing transmissive light
35   modulators include Ogawa, U.S. Patent No. 5,321,448, and
Nakayama et al., U.S. Patent No. 5,626,409, the latter of
which describes a system which is the transmissive

equivalent of the system in FIG. 1. The light from the
lamp is divided into the three-color paths by a set of
dichroic filters. After passing through the three light
valves, the modulated light distributions are recombined
5   using a separate set of dichroic filters. The '448
reference uses a set of dichroic filters to divide the
lamp output into the three-color paths, and a separate
set of dichroic filters, in the form of a color cube
prism, to recombine the modulated light. This later
10   configuration is the most common architecture presently
used for transmissive light valves.

    2.   Polarization Converters

    Projection displays that are based on
polarization modulating devices, such as LCDs, include as
15   a necessary step in the LCD illumination process the
polarization of the light collected from the system light
source. The polarization state required is typically
linear with the direction of polarization aligned to a
preferred orientation of the light modulator (called the
20   director in an LCD). A typical polarizing arrangement is
shown in FIG. 9. Light from the source is passed through
a PBS which consists of a pair of prisms assembled to
form a cube. A special dielectric coating is deposited
on the diagonal of one of these prisms and sealed between
25   the two pieces of glass when the prisms are glued
together. The dielectric coating strongly reflects light
whose electric field vector is aligned perpendicular to
the plane of the drawing in FIG. 9. This light is
typically given the designation s-polarized. Light whose
30   electric field vector is parallel to the plane of FIG. 9,
typically called p-polarized, is strongly transmitted by
the dielectric coating. The light produced by the vast
majority of useful light sources is randomly polarized,
consisting of an equal combination of s-polarized and
35   p-polarized light. Thus, in a PBS, 50% of the light
output reflects as s-polarized and 50% of the light
transmits as p-polarized. For a single wavelength of

light, it is possible to devise a coating that produces
exact polarization separation, i.e., no p-polarization
reflects and no s-polarization transmits. However, over
the broad visible spectrum, inefficiencies of the coating
5   structure limit the degree of polarization obtainable.

In many projection display systems, light from
the system source is polarized to the direction required
by the light modulators, and the remaining light,
polarized perpendicular to the preferred direction, is
10   simply discarded. This represents a substantial
performance reduction since half of the light produced by
the source is not useable in the system. A number of
different techniques of polarization conversion have been
devised in an attempt to recover the performance loss
15   caused by the polarization process. These polarization
converters, sometimes called polarization recyclers,
employ various techniques to realign the polarization
state of the discarded light to be parallel to the
desired polarization state for the light modulators, and
20   to add that light back into the illumination system. The
setup shown in FIG. 10 implements polarization conversion
using only reflection from planar mirror surfaces to
accomplish the conversion. The light from a lamp is
split into the s and p polarizations by the beam splitter
25   plate (element 302). The s-polarization is oriented in
the "horizontal" direction of the perspective drawing.
This part of the light distribution is reflected by two
mirrors (elements 325 and 326) and remains as an
s-polarized distribution when it is incident on the upper
30   part of the illumination region 308. The p-polarized
distribution is initially oriented in the "vertical"
direction, but reflection from mirror element 323
re-orients this polarization in the "horizontal" plane.
A second reflection of this newly s-polarized
35   distribution by mirror element 324 does not effect the
direction of polarization and this distribution reaches
the lower part of the illumination region 308 as an

s-polarized distribution.   If we assume a reasonably
efficient polarizer with 100:1 polarization ratio, then
the setup of FIG. 10 results in approximately 99% of the
lamp output incident in the illumination region 308 with
5   the desired, horizontally oriented, s-polarization.

  The setup shown in FIG. 10 implements the
polarization conversion, but it also illustrates one
consideration that must always be taken into account with
polarization converters.   The illumination region 308 has
10   twice the area of the illumination region that would be
covered by either the s-polarized or p-polarized light
distributions prior to conversion.   One could certainly
adjust the mirror elements 324 and 326 to cause the two
sub-regions to overlap with the same area as the original
15   lamp output.   But, this adjustment would cause the
angular distribution of light rays incident on the region
to increase.   It is a fundamental property of optical
systems in general and illumination systems in
particular, that, once established, the product of the
20   illumination area and the angular extent of the
illuminating rays is an invariant.   In an illumination
system this invariant is generally referred to as the
étendue.   In the optical system of FIG. 10, the étendue
is established by the lamp, and is dependent on the
25   nature of the reflector and the physical size of the arc
source used in the lamp.   The process of splitting the
two polarization states apart with the beam splitter
plate effectively produces a second source as seen by the
rest of the optical system.   Since the étendue is a
30   geometrical optics property rather than a physical or
wave optics property, it does not depend on polarization
states.   Thus, the effective second source has the same
étendue as the original lamp and the total étendue in the
rest of the system is twice that of the original lamp.
35   It is clear in FIG. 10 that the net étendue is doubled
since the area illuminated is doubled.   In the case of
adjusting the mirrors to cause the illumination region to

have the same area as the original beam, the étendue
doubles due to a doubling of the angular extent of the
illuminating rays. In either case, the étendue of the
output of a polarization converter is twice that of the
5   input randomly polarized input.

A potential problem with this doubling is that
the optics after the illumination system may not be able
to handle the larger étendue. If the étendue of the rest
of the optical system is equal to or greater than that of
10   the polarization converted illumination distribution,
then all of the illumination distribution is usable. In
this case, the system throughput would be essentially
doubled relative to a system that did not employ
polarization conversion. If the étendue of the rest of
15   the optical system is smaller than that of the
polarization converted illumination distribution, then
some of that light will be lost. The loss results from
either overfilling the area of the usable field of view
in the remaining optical system or by overfilling the
20   numerical aperture of the remaining optics. In this
case, the increase in system throughput would be less
than the twofold improvement in the fully étendue matched
configuration. In the extreme case where the étendue of
the rest of the optical system is just matched to the
25   étendue of the original lamp output, there would be no
gain in system throughput, since all of the converted
light would fall outside the usable area or numerical
aperture of that optics.

The polarization converter of FIG. 10 has the
30   advantage of being implemented with very simple
components, namely a polarizing beam splitter and front
surface mirrors. The disadvantage is the number of
components involved--a beam splitter and four mirrors.
This can lead to packaging and size problems. A much
35   more common method of implementing polarization
conversion requiring fewer components is shown in
FIG. 11. In this system, a polarizing beam splitter is

again used to separate the s and p polarization states.
The s-state light reflected from the beam splitter
surface is reflected again by a mirror (or by another
polarizer reflecting s-state light) so that its

5   propagation direction is the same as the transmitted
p-state light. The s-state light is then passed through
a special crystalline optical component called a half
waveplate. The half waveplate is made of a material that
has different refractive indices along the different

10 directions of its crystalline structure (a characteristic
called birefringence). The propagation velocity of light
through the material depends on the refractive index.
Light polarized in the direction of the crystal axis with
the highest index will propagate slower than the light

15 polarized perpendicular to this axis. This axis is
called the principle axis of the crystal (sometimes
called the extraordinary axis). If linearly polarized
light enters the half waveplate with its polarization
direction making an angle with respect to the principle

20 axis, then the light can be described as the sum of a
component along the principle axis and a component
perpendicular to the principle axis. The component
parallel to the principle axis is delayed or retarded due
to the slower propagation velocity, and this delay causes

25 the net direction of polarization of the light
distribution to rotate. In the case of a half waveplate,
linearly polarized light making an angle θ with the
principle axis on entering the waveplate will be rotated
by 2θ upon exiting. If the waveplate in FIG. 11 is set

30 to have its principle axis at 45 degrees relative to the
direction of the s-polarized light, then the polarization
will rotate by 90 degrees and will be parallel to the
p-polarized light transmitted by the beam splitter. The
illuminated object now receives only p-polarized light

35 (within the efficiency limits of the beam splitter). It
should also be clear from the figure, that the étendue of
the illumination distribution at this object is again

twice that of the original lamp output due to the larger
illumination area.

A slight modification of this setup is shown in
FIG. 12 in which the mirror and waveplate are tilted to
5   bring the two illumination patches together. It is clear
in this figure that, although the illuminated area is the
same as with the original lamp, the angular extent of the
illuminating rays has increased. Analysis of this
distribution would reveal that the étendue has again
10   doubled.

Another technique for polarization conversion
uses a pair of polarizing beam splitters, a quarter
waveplate, and a mirror. This method is illustrated in
FIG. 13. The unpolarized light from a lamp is passed
15   through one beam splitter where it is again split into its
s-polarized and p-polarized components. In the
configuration illustrated in FIG. 13, the s-polarized
component goes directly to one region of the illuminated
object. The p-polarized component of the lamp output
20   passes into a second beam splitter where it again passes
through the splitting surface. This light then passes
through a quarter waveplate. A quarter waveplate, like
the half waveplate described above, is a birefringent
crystal that will introduce delays or retardations to the
25   light passing through it. If linearly polarized light
enters the waveplate with its direction of polarization at
45 degrees to the principal axis of the crystal, then the
output light will be circularly polarized. The
"handedness" of the circular polarization depends on the
30   exact relationship between the direction of the waveplate
principal axis to the light polarization, but this is not
important for the polarization conversion process
described here. The circularly polarized output of the
waveplate then hits a mirror, where it reflects back
35   through the waveplate. When circularly polarized light
reflects from a plane mirror, the handedness (whichever
direction it is) is reversed. This reflected light passes

back though the quarter waveplate, where it is converted
into linearly polarized light by the retardations of the
birefringent crystal. However, the handedness of the
circularly polarized light passing back through the

5   crystal to the left is reversed from that of the light
that exited the waveplate on its first pass. The
resulting linear polarization of the light exiting the
quarter waveplate to the left will therefore be
perpendicular to that of the light entering the waveplate

10 to the right. The p-polarized light that enters the
quarter waveplate is thus converted into s-polarized light
upon reflection from the quarter waveplate/mirror
combination. This light then reflects from the polarizing
surface of the second beam splitter and falls on another

15 portion of the illuminated object. As in the previous
methods of conversion, the illuminated area doubles
relative to the original lamp output, or the light can be
redirected to illuminate the same area with a doubling of
the angular extent of the illuminating distribution. In

20 either case, the étendue has doubled.

        A practical implementation of polarization
conversion in conjunction with a fly's-eye integrating
illumination system is shown in FIG. 14A and the complete
projector system using this illuminator is shown in

25 FIG. 14B. The fly's-eye lens arrays are used to produce a
uniform rectangular illumination distribution at the LCLV.
An array of polarizing beam splitters is introduced into
this setup where the first lens array brings light to
focus. As can be seen in the enlargement in FIG. 14A, the

30 PBS array consists of polarizing beam splitters and half
waveplates to convert essentially all of the light to
s-polarization. This conversion process is identical to
that implemented by the setup in FIG. 10.

        Another type of polarization converter is

35 disclosed in Heynderickx, et al. U.S. Patent No.
5,626,408. This patent describes a system in which
cholesteric filters are used to split up the output of a

lamp into the red, green, and blue color channels needed for a three-panel LCD projector. A polarization conversion technique appropriate for cholesteric filters is implemented in this system. Referring now to FIG. 1 of that patent, light from a lamp 3 is directed into an illumination system. The first element of that system is a cholesteric filter 9. Color filter 9 reflects red light with right handed circular polarization and transmits all the rest of the lamp output. The reflected red light is directed to a mirror 15 where it reflects directly back to the cholesteric filter. The reflection of the light at the mirror changes it into left handed circular polarization and this light passes through the cholesteric filter toward element 63. The next cholesteric filter 10 reflects red light with left handed circular polarization and directs that light toward element 63. All of the red light from the lamp output has now been converted into left handed circularly polarized light. Element 63 is a quarter waveplate that converts this light into linear polarization that is required by the LCD modulator 27. The blue and green portions of the lamp output are converted into left handed circular polarization in an identical process using cholesteric filters 11 and 12 for green and filters 13 and 14 for blue. Quarter waveplates 65 and 67 convert the circularly polarized distributions into the linear polarizations needed by the LCD modulators 29 and 31.

Heynderickx, et al., also disclose a composite circular polarizer for converting unpolarized light into two polarized beams. The polarized beams are then reflected by cholesteric filters toward LCD modulators.

Takanashi et al., U.S. Patent 5,122,895, describe a polarization converter using a pair of cube polarizing beam splitter and a quarter waveplate/mirror component identical to that of FIG. 13. A key feature of this invention is that the quarter waveplate is made an active component by implementing it with a liquid crystal

or other electro-active optical material. This allows the conversion process to be switched on and off with a control signal.

Takanashi, et al., U.S. Patent 5,164,854,
describe several implementations of polarization converters for a reflective LCD projection system. The implementations include a beam splitter half waveplate configuration essentially identical to that of FIG. 11 and a non-switchable quarter waveplate implementation essentially identical to that of FIG. 13. In all cases in this patent effort was made to realign components to direct the converted polarized light to a small illumination area with the corresponding increase in angular distribution of the light.

Karasawa, et al., U.S. Patent 5,200,843 and
Karasawa, et al., U.S. Patent 5,278,680 describe implementations of all three types of converters shown in FIGS. 10-12.

Nicolas et al., U.S. Patent 5,299,036, describe
a projector that uses two full color LCD modulators. A beam splitter divides the light to the two modulators and one path has a half waveplate to rotate the polarization to be properly aligned with the LCD director. The rest of the optical system is involved with recombining and aligning the two projected LCD panels. Although this uses two separate modulators the concept is similar to the beam splitter/half waveplate conversion method of FIG. 11.

Blanchard, et al., U.S. Patent 5,303,083,
describe a polarization converter that has features of both the beam splitter/half waveplate configuration of FIG. 11 and the beam splitter/quarter waveplate configuration of FIG. 13. The light normally lost from a polarizing beam splitter is first converted into circular polarization by a quarter waveplate, reflected by a 45 degree mirror, and then passed through a second quarter waveplate to produce linear polarization in the same direction as the desired output from the beam splitter.

Shingaki et al., U.S. Patent No. 5,381,278, and Mitsutake, et al., U.S. Patent No. 5,566,367, describe a number of polarization conversion techniques that are essentially equivalent to the beam splitter/half waveplate method and the beam splitter/quarter waveplate method described in the previous section. These patents also describe arrays of small conversion prism structures that are used in conjunction with fly's-eye integrators in a projector illumination system. The configuration of the array of converters is similar to that of the system shown in FIG. 14.

Kato, U.S. Patent 5,653,520, describes a large multi-segment converter using beam splitters and half waveplates. The configuration is intended for use with large LCD panels and its multiple segments are used to achieve full conversion and uniform illumination over a large light modulator. The conversion process is identical to that of the beam splitter/half waveplate process.

Miyatake et al., U.S. Patent 5,657,160, describe a method of polarization conversion that is affected purely by reflections from plane mirrors without using waveplates. The process is essentially equivalent to the process described in FIG. 10. The patent also describes an array of small converters using this process that employs internal reflections inside small prism structures. This structure is also used in conjunction with fly's-eye integrators in a projector illumination system.

All of the aforementioned polarization converters described above convert all of the light output of a lamp, in all three-color bands, into a single linear polarization state. Heynderickx et al., U.S. Patent 5,626,408, mentioned as the exception above is the only patent that describes treating colors separately, but this was done only to implement the color splitting with cholesteric filters. The system described in that patent

ultimately put all three-color bands into the same linear polarization state.

Accordingly, there is still a need for a projection system for reflective liquid crystal light valves that has a small back working distance for the projection lens, that has a projection path free from crossed dichroics obstructions, that has a relatively simple configuration of the components that are used to split up and recombine the three color light distributions, includes an efficient polarization converter for higher brightness applications, that is more compact than known projection systems, and that may be manufactured at a reduced cost compared to existing systems.

SUMMARY OF THE INVENTION

The present invention provides a polarization converter for use with a light source that generates a light beam having at least two light components. The polarization converter comprises an optics array capable of separating the light beam into at least two light components having different polarizations. The polarization converter has at least one or more of the following advantages. The polarization converter provides for light components having different polarizations, and increases the amount of transmitted light. In preferred embodiments of the polarization converter, the étendue of the polarization converter is no more than 3-1/2 times, and in some embodiments only 2 times, the étendue of the light source. Certain embodiments of the invention provide for small geometries and simple optics.

The present invention also includes a method for converting light, comprising producing a light beam that is non-polarized and has at least two light components. The light is separated into at least two light components having different polarizations. Substantially all of the light beam is transmitted by the polarization converter.

The present invention further includes a projection display system for reflective light valves comprising a light source for generating a light beam having at least two light components wherein the light components are polarized and at least one of the light components is polarized differently than another of the light components. A projection system has plural polarized beam splitters and dichroic filters therein, wherein each polarized beam splitter and dichroic filter reflects at least one of the light components and transmits at least another of the light components, and a plurality of LCD panels, each LCD panel generating a light-component-specific image associated with one of the light components. In addition, the projection display system has a projection lens for projecting an image combined from the light-component-specific images from the LCDs.

In another aspect of the invention, a projection display system using polarized light comprises a light source for generating a light beam having at least two light components, wherein the light components are polarized and at least one of the light components is polarized differently than another of the light components. The display system has a projection system having a plurality of polarized light modulators, each modulator generating a light-component-specific image associated with one of the light components. The display system also has a projection lens for projecting an image combined from the light-component-specific images from the modulators.

The projection display systems of the present invention have one or more of the following advantages: a small back-working distance from the projection lens; a projection path free from crossed dichroic obstructions; a relatively simple configuration of components used to split up and recombine the three-color light

distributions; compact size; and reduced manufacturing cost compared to existing systems.

The foregoing and other objectives, features, and advantages of the invention will be more readily
5   understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

10 BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIGS. 1-3 depict examples of prior art projection display systems.

FIG. 4 is a schematic representation of the optical path of the projection system of the invention.
15 FIG. 5 is a schematic representation of a first embodiment of a light source and the projection system of the invention.

FIG. 6 is a schematic representation of a filter stack of the invention.
20 FIG. 7 is a schematic representation of a first embodiment of a projection display system of the invention.

FIG. 8 is a schematic representation of a second embodiment of a projection display system of the
25 invention.

FIG. 9-14 depict examples of prior art polarization converters.

FIG. 15 shows a block diagram for a method of converting spectrally distributed polarized light
30 according to the present invention.

FIG. 16 is a schematic representation of an embodiment of a spectrally distributed polarization converter of the present invention.

FIG. 17 is a schematic representation of another
35 embodiment of a spectrally distributed polarization converter of the present invention.

FIG. 18 is a schematic representation of another embodiment of a spectrally distributed polarization converter of the present invention.

FIG. 19 is a schematic representation of another embodiment of a projection display system of the present invention.

FIG. 20 is a schematic representation of another embodiment of a projection display system of the present invention.

FIG. 21 is a schematic representation of yet another embodiment of a projection display system of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

1.   Projection Display System

An exemplary embodiment of the projection display system of the present invention is shown generally at 80 in FIG. 4.   System 80 includes a light source 82 and a projection system 83.   Projection system 83 includes two dichroic filters (DF) 84, 86, and two polarizing beam splitters (PBS) 88, 90, to split up the incoming white light from light source 82 into red-green-blue (RGB) components before directing each light beam component to a specific light valve, or liquid crystal display (LCD), 92, 94, 96.   LCDs 92, 94, 96 each provide a light-component-specific image, which is illuminated by the light beam component and reflected from the face of the LCD, carrying a color image component.   The color image components are then recombined, and the reflected light is directed to projection lens 98.

A requirement for proper operation of projection system 83 is that the input illumination is pre-filtered and polarized so that the green and blue distributions are s-polarized and the red distribution is p-polarized.   As is known to those of skill in the art, s-polarized light has its electric field vector linearly polarized perpendicular to the plane of the figure and p-polarized

light has its electric field vector linearly polarized in the plane of the figure. The pre-filtering mechanisms will be described later herein.

DFs 84 and 86 are arranged in a substantially
5   straight line within projection system 83, as are PBSs 88, 90. The DFs and PBSs are arranged to intersect their respective substantially straight lines adjacent the midpoints thereof in a normal relationship. Put another way, the optics are arranged in a substantially "X" shaped
10   configuration, with the filters and beam splitters each joined adjacent an edge thereof. The coated surfaces line up in the "X" shaped configuration.

In projection system 83, the incoming light first encounters blue-transmitting dichroic filter 84.
15   The s-polarized blue light is transmitted while the s-polarized green light and p-polarized red light are reflected. The blue light passes on to PBS 88 where, because it is s-polarized, it reflects to first LCD light valve 96, which is a blue light modulator. LCD 96
20   modulates the polarization of the light by rotating the direction of polarization in proportion to the electrical signals provided to the device. The reflected light is thus a combination of s-polarized and p-polarized light. When the reflected light returns to PBS 88, the
25   s-polarized portion again reflects back toward the incoming illumination and the p-polarized portion is transmitted on to blue-reflecting dichroic 86. The blue light will reflect off second dichroic filter 86 and through projection lens 98, to an image display, such as a
30   projection screen.

The green and red light that is reflected by first dichroic filter 84 propagates to second PBS 90. The p-polarized red light is transmitted through PBS 90 to second LCD 92, a red light modulator, while the
35   s-polarized green light is reflected to third LCD 94, a green light modulator. LCDs 92, 94 modulate the light distributions, and after the reflected distributions

return to PBS 90, only the p-polarized portion of the
green light and the s-polarized portion of the red light
pass over to blue-reflecting dichroic filter 86. The
other portions of these two distributions are again
returned toward the incoming illumination. Because
dichroic filter 86 transmits both red and green, these two
distributions are combined with the blue light from the
other path and pass through projection lens 98 to the
image display. Dichroic filter 86 acts as an image
recombiner in this embodiment.

It may be seen in FIG. 4 that the light path
from any LCD to projection lens 98 encounters one and only
one PBS and one and only one dichroic filter. The optical
path length has been reduced to a minimum of twice the
active width of the LCD panel. Reflective LCD panels
typically used in projection systems of the type described
herein typically vary in size from approximately 7 mm to
5 cm, diagonal measurement. The optical path length is
typically no less than approximately 1.6 cm to 14 cm. In
this configuration, however, it is not necessary to cross
any color filtering or polarizing structure in the optical
path. There is, therefore, no obstruction of any kind in
the projection path as in the configurations of FIG. 3.
This represents a significant performance advantage. The
configuration of FIG. 4 may also be implemented easily
with thin plate dichroics and PBSs, which represents a
significant cost advantage over a cube prism
configuration.

Projection display system 80, as shown in
FIG. 5, includes projection system 83 of FIG. 4, and a
specific embodiment of a pre-filtering illumination
mechanism required to obtain the special combination of
input light for the proper operation of this architecture.
Light source 82 includes a lamp 100 and reflector 102, and
a number of DFs and PBSs. An unpolarized white light beam
from lamp 100 is incident on a red-transmitting dichroic
filter 104. The blue and green light from the lamp

reflect from filter 104 to a PBS 106. The s-polarized
portions of the green and blue light then reflect off the
PBS toward a red reflecting dichroic filter 108, while the
p-polarized green and blue portions are absorbed by a stop
5   109. . The two distributions that pass through dichroic
filter 108 provide the s-polarized blue and green input to
projection system 83. The unpolarized red light
transmitted by dichroic filter 104 is polarized by PBS
110, and the s-polarized portion is reflected toward
10   red-reflecting dichroic filter 108, while the p-polarized
red portion is absorbed by stop 111. Before impinging the
dichroic, the light passes through a half wave plate 112
that rotates its polarization direction by 90 degrees.
The red light is now p-polarized, reflects off red-
15   reflecting dichroic 108 and provides the p-polarized red
light input to projection system 83.

The pre-filtering configuration has the
advantage of being implemented with fairly standard and
inexpensive filtering components. One disadvantage of
20   this arrangement is that the portions of the light
distributions that pass through PBSs 106, 110 and hit
stops 109, 111, respectively, are absorbed and lost. This
light is half of the total light output from lamp 100.
This level of light loss is typical of LCD projection
25   systems that do not use polarization converters or
recyclers. A second disadvantage is the additional size
of the pre-filtering optics adding to the whole system.
While the size of this complete system is smaller than the
original reflective architecture described in FIG. 1, that
30   uses simple plate filters and PBSs, it is quite a bit
larger than the configurations of FIGS. 2 or 3.

A solution to the size problem may be found in
another embodiment of the pre-filtering optics, as shown
in FIGS. 6 and 7. Referring now to FIG. 6, an embodiment
35   of a light source filter stack is shown generally at 113.
Filter stack 113 uses specially designed cholesteric color
filters 114, 116, 118. Cholesterics are chemical

structures which have a spirally twisted molecular alignment. These materials have a special optical property that causes light of a wavelength that is equal to the pitch of the cholesteric spiral to be completely reflected if the light is circularly polarized, with the direction of circularity being the same as the direction of the cholesteric spiral. Thus, a cholesteric filter may be set up to reflect the left or right handed circular polarized portion of one color of light and to transmit the other handedness. The cholesteric does not affect any other color of light, transmitting both polarizations. The chemical structures of cholesterics may be manipulated to cause this special reflecting property to extend over a fairly broad range of wavelengths. The bands may be tuned to give just about any desired color passband for the portion of light that is reflected.

The pre-filtering operation of filter stack 113 is as follows: Unpolarized white light is incident on the stack from the left. First filter 114 is designed to reflect the right-handed circularly polarized portion of red light, and transmit the left-handed circularly polarized portion of the red light, and all polarizations of green and blue light. Second filter 116 is designed to reflect the left-handed polarization portion of green light. The right-handed polarization portion of green light is transmitted along with the left-handed polarized portion of the red light and the unpolarized blue light. Third filter 118 is designed to reflect the left-handed polarization portion of blue light, and transmits the right-handed polarization portion of blue and the rest of the incident light i.e., the right-handed polarization portion of green light and the left-handed polarization portion of red light.

Circular polarization may be turned into linear polarization by passing the light through a quarter wave plate 120. Right-handed polarized light will exit wave plate 120 as linearly polarized with the direction of

polarization at +45 degrees to the crystalline optic axis of the wave plate material. Left-handed polarized light will also exit the wave plate linearly polarized, but the direction will be at - 45 degrees to the crystalline axis.
5   Thus, with proper orientation of the wave plate axis, the right-hand polarized green and blue light will exit as s-polarized and the left-hand polarized red light will exit as p-polarized. This is the desired input to the imaging portion of the projection architecture.
10   The system shown in FIG. 7 uses pre-filtering stack 113 as part of light source 82 directly after lamp 100 to implement complete projection display system 80. System 80 is significantly smaller than the arrangement made with more conventional components in FIG. 5. The
15   smaller size is the main advantage of this embodiment. This configuration has the same light loss problem as that of FIG. 5 because the cholesterics reflect half of the unpolarized light in their passband. This is again typical in many LCD projectors. Another disadvantage is
20   the relative immaturity of the cholesteric materials. It is not clear at this point if the filtering materials will be as efficient or as durable as the dielectric stack materials used in dichroic filters and in PBSs. The system of FIG. 7 is a preferred embodiment if those
25   questions may be satisfactorily answered.
          The embodiment of projection system 83 of system 80 is the preferred embodiment. There are, however, alternative methods of arranging the color and polarization distributions. As an example, if the first
30   dichroic 84 in FIG. 4 is changed to red-transmitting and the second dichroic 86 is changed to red-reflecting, then the pre-filter must polarize green and red light with s-polarization and blue with p-polarization. In this case, the roles of LCD 92 and LCD 96 in modulating the red
35   and blue light distributions are reversed, but in all other respects the system is equivalent. It is, however, undesirable to set this type of system up with the

dichroics being green-reflecting and green-transmitting, which will have LCD 96 modulating the green light. Green dichroic filters have two band edges in the visible spectrum—one separating red and green and the other

5   separating blue and green. The position of the band edges is highly dependent on the polarization of the light. If green dichroics are used, either red or blue light will have to be polarized in the opposite state from the green light and the filtering at the band edge between the two

10 differing polarization states will be poorly controlled. In the system shown in FIG. 4, using blue dichroics, the band edges of both filters separate blue and green. Both of these light distributions have the same polarization when they are split apart by the first, bluetransmitting

15 dichroic, and when they are recombined by the second, blue-reflecting dichroic. The filtering at the band edge in both filters may therefore be well controlled. The same is true if red dichroics are used.

   Projection display system 122, depicted in

20 FIG. 8, includes a projection system 124 having, in addition to the components of projection system 83, a blue-transmitting dichroic filter 126, located prior to projection lens 98, which replaces blue-reflecting filter 86 shown in FIG. 7. The result is to direct the recombined

25 light distributions out of projection system 124 at ninety degrees from that of projection system 83 of FIG. 7. This alternative embodiment may offer packaging advantages for some products. It should be noted that the band edge of first blue transmitting filter 84 in FIG. 8 is used to

30 separate s-polarized blue and green light, while the second blue transmitting filter 126 is used to recombine p-polarized blue and green light. For reasons mentioned in the previous paragraph, these are not identical filters.

35   2.   Spectrally Distributed Polarization Converter

   The present invention further provides a method and apparatus for converting light into two separate light

components, each of the light components having different
polarizations. As used herein, a light component refers
to different color or spectral bandwidths, such as red,
blue or green light components. As discussed above in
5   connection with the pre-filtering required for projection
display systems utilizing polarization light, the
throughput of the system may be enhanced by using a
polarization converter. The projection system of the
present invention requires the polarization of one of the
10   light components to be polarized differently than the
polarization of another light component, but the prior art
polarization converters do not provide the required
polarization. The different polarizations are preferably
at 90-degree orientations but may be at any other suitable
15   angle or relationship, as desired. Also, right- and
left-hand circular polarizations may be used. It is also
to be understood that any set of wavelength ranges may be
used for the light components, as desired. Also, any
number of light components may likewise be used, as
20   desired. Accordingly, the present invention further
provides a spectrally distributed polarization converter
to provide pre-filtering for the requisite polarization
for each light component.

        Referring now to FIG. 15, the first step
25   involves producing a light beam that is nonpolarized and
has at least two light components. The next step involves
separating the light into two light components having
different polarizations, with substantially all of the
light beam being transmitted.

30   The second step may be accomplished in a variety
of ways. In one method, the light is first separated into
a first polarized component having a first polarization
and a second polarized component having a second
polarization. Next, the first polarized component is
35   spectrally separated into the first light component and
the second light component. The polarization of the first
light component is then changed to the opposing second

polarization. Likewise, the second polarized component is spectrally separated into the first light component and the second light component. The polarization of the second light component is changed to the first

5   polarization. As a result, all light of the first light component has the second polarization, and all of the light of the second light component has the first polarization.

Several optical systems may be employed to carry

10   out the method illustrated in FIG. 15. FIG. 16, for example, illustrates one such simple optical system. The polarization converter 200 is used with a light source 202 that produces nonpolarized white light having red, green, and blue components. The converter 200 has an optics

15   array 204 for separating the white light into at least two color components having different polarized states. The white light first encounters polarizing beam splitter 206, which reflects light polarized in the s-direction and transmits light polarized in the p-direction.

20   The transmitted p-polarized component then encounters a dichroic filter which reflects the blue and green components and transmits the red component. The red component continues to folding mirror 210, which is aligned at a forty-five degree angle. The red component

25   then passes through half waveplate 212, which converts the red component from p-polarized to s-polarized.

Likewise, the s-polarized light reflected by beam splitter 214 is transmitted to a dichroic filter 214 which reflects the blue and green components and which

30   transmits the red component. The blue and green components are reflected toward the folding mirror 216, which then transmits the blue and green components through another half waveplate 218. The half waveplate 218 changes the polarization of the blue and green components

35   from s-polarized to p-polarized.

Each of the separated light components then exit the optics array 204 and are directed toward an

illuminated object, which could be another optical system
or lens. As can be seen, the optics array 204 transmits
nearly all of the light produced by the light source 202,
except for transmission losses occurring as a result of
5   passing through or reflecting from the optics themselves.
Thus, substantially all of the light produced by the light
source 202 is transmitted through the optics array 204.
As can be seen, the optics array in FIG. 16 results in a
four fold increase of the étendue of the light source 202.

10   FIG. 17 illustrates a more efficient spectrally
distributed polarization converter 230. The light from
the light source 232 enters optics array 234 and is
divided into its s- and p-polarizations by a polarizing
beam splitter 236. The p-polarized white light passing
15   through the splitting surface exits beam splitter 236 and
passes through a quarter waveplate 238, turning it into
circularly polarized light. This distribution then hits a
dichroic filter 240 that reflects the blue and green
components, but transmits the red component. The
20   reflected blue and green components pass back through the
first quarter waveplate 238 and are converted back into
linear polarization, but now aligned in the s-direction,
having been rotated by 90 degrees due to passing twice
through the quarter waveplate 238. The blue and green
25   components return to the splitting surface of beam
splitter 236 where they are reflected, exiting the beam
splitter 236 and falling on the illuminated object 258.
The red component that was transmitted by the dichroic
filter 240 passes through another quarter waveplate 242
30   whose optical axis is aligned with the first waveplate
238. The red component passing through quarter waveplate
242 is also converted into s-polarization. The
s-polarized red component enters a second beam splitter
254 where it is reflected at the splitting surface and
35   exits the beam splitter 254. It then passes through a
half waveplate 256 where its polarization is rotated by 90

degrees to be p-polarized and it also falls on the illuminated object.

In contrast, the s-polarized light from the light source 232 reflects from the splitting surface of the beam splitter 236. The s-polarized light exits the beam splitter, passes through a quarter waveplate 244, which circularly polarizes the light. The light then hits a second dichroic filter 246, which reflects the red component and transmits the blue and green components. The reflected red component passes back through the quarter waveplate 244 converting the red component into p-polarized light. This red component returns to the splitting surface of the beam splitter 236 and combines with the s-polarized green and blue components reflected from stack of the quarter waveplate 238 and dichroic filter 240. The p-polarized red component exits the beam splitter 236 and illuminates the same portion of the illuminated object 258 as the s-polarized blue and green components.

The blue and green components that are transmitted by the dichroic filter 246 pass through another quarter waveplate 248, which also has its optical axis aligned with quarter waveplate 244, thus converting the blue and green components into p-polarization. The blue and green components then reflect off of two mirrors 250 and 252 that redirect the blue and green components into the beam splitter 254. Thus, dichroic filter 246 is optically interposed between beam splitters 236 and 254. Since these blue and green components are p-polarized they pass through the splitting surface of the beam splitter 254 where they combine with the s-polarized red component transmitted by the dichroic filter 240. The blue and green components exiting from beam splitter 254 pass through a half waveplate 256, which converts them into s-polarized light, and illuminate the same portion of the illuminated object 258 as the p-polarized red components.

The configuration shown in FIG. 17 converts
all of the red light from the light source 232 into
s-polarization. It is clear from the figure that, similar
to the conventional polarization converters, the étendue
5   is doubled by this conversion process. Tilting various
components in this configuration can bring the two
illumination distributions together. This will result in
the area of the illuminated region being the same as the
original lamp output. This will also increase the angular
10   distribution of the illumination, again doubling the
étendue.

An alternative embodiment of this concept that
is suitable to implementation in projectors with fly's-eye
illumination optics is shown in FIG. 18. In this
15   configuration, converter 260 has an optics array 264
comprised of a stack 266 of polarizing beam splitters
266a-g similar to the conventional converter shown in
FIG. 14. In FIG. 18, light entering the beam splitter
stack 266 through input 262a is divided into its two white
20   light polarization states. The p-polarization passing
through the splitting surface of PBS 266b enters another
stack of aligned quarter waveplates 270a, 274a and a red
reflecting dichroic filter 272a. The blue and green
components that are transmitted by the dichroic filter
25   272a exit as s-polarized distributions due to the
operation of the two quarter waveplates 270a and 274a.
The red component reflected by the dichroic filter 272a is
also converted into s-polarization. This red component
returns to the splitting surface of PBS 266b where it is
30   reflected up to another splitting of surface PBS 266a in
the next beam splitting section. The red component again
reflects from the splitting surface of PBS 266a and
propagates to the left in the figure. The red component
then passes through a quarter waveplate 276a, reflects
35   from a metal mirror 278a, passes back through the quarter
waveplate 276a and re-enters the beam splitter 266a. The
action of the quarter waveplate 276a rotates the

polarization direction so that it is now p-polarized. This red component now passes through the splitting surface of PBS 266a and out the beam splitter as the desired p-polarized red component.

5   The s-polarized white light that reflects from the splitting surface of PBS 266b reflects again from the next lower splitting surface of PBS 266c and then passes into another aligned quarter waveplate/dichroic filter stack consisting of quarter waveplates 280a and 284a and

10   dichroic filter 282a. The dichroic filter 282a in this stack transmits red light and reflects green and blue and the quarter waveplates 280a and 284a convert all three of these components into p-polarization. The red component that is transmitted by the dichroic filter 282a is the

15   rest of the desired p-polarized red light. The blue and green components that are reflected from the second dichroic filter 282a are converted back to s-polarization by first passing through the beam splitting surface of PBS 266c and then passing through the quarter waveplate 276b,

20   reflecting off the metal mirror 278b, and passing through the quarter waveplate 276b. After passing through the waveplate 276b it now s-polarized green and blue components reflect off of two more polarizing splitting surfaces of PBS 266c and 266d and exit as the remainder of

25   the desired s-polarized green and blue components.

        Similarly, the converter 260 has quarter waveplates 270b and 274b, dichroic filter 272b, quarter waveplate 276c, metal mirror 278c, and quarter waveplates 280b and 284b, and dichroic filters 282b which operate in

30   the same fashion as described above for like elements having the same reference numerals. As can be seen, the various optics may be repeated to provide for additional light inputs such as 262a and 262b.

        In this embodiment, for the single input, there

35   are four polarizing sections and the output is four separate components. The étendue of this output is four times greater than that of the input. However, the

configuration shown in FIG. 18 has two inputs 262a and
262b for unpolarized white light. The operation of the
beam splitters, waveplates, dichroic filters and metal
mirrors is identical on this second input 262b as on the
5   first input 262a described above. In the combination it
can be seen that there is an overlap of the operations in
one of the beam splitters, namely PBS 266d. The
s-polarized green and blue components from the first input
262a combine with the p-polarized red component from the
10   second input 262b. If all of the light from a light
source is gathered and sent into these two inputs, then
the resulting change in étendue is a 7 to 2 increase
rather than a 4 to 1 increase. If three light inputs are
used the increase is 10 to 3, and so on, with the general
15   result for the N inputs being an increase of 3N +1 to N.
Thus, for a large number of segments the étendue is a
factor of three. The typical number of light inputs in a
fly's-eye lens illuminator would be six or eight, so the
increase in étendue would be approximately 3.2 for either
20   case. Although this is larger than the twofold increase
of the conventional polarization converter, it is still
useful for larger LCD panels and for use with very small
arc sources.

FIGS. 17 and 18 are the preferred embodiments.
25   The first would be most useful in a system where no
fly's-eye lens illumination was being employed and the
second would be the preferred configuration for fly's-eye
illuminators. The alternatives for this invention involve
different specifications on the passband characteristics
30   of the dichroic filters. The examples used to illustrate
the process of producing s-polarized green and blue
component and p-polarized red component are useful for one
configuration of a reflective LCD projection system.
Another configuration of this type of projector might
35   require the green and red components to be s-polarized and
the blue component to be p-polarized. The distribution of
colors and polarizations is controlled by the dichroic

passbands and must be matched to the requirements of the
optical system being illuminated.

In addition, while the polarization converter of
the present invention may be used to separate light into
5 red, blue and green components, other color components
could be chosen as well by simply selecting the
appropriate optics. For example, the spectrally
distributed polarization converter could be configured to
separate the light into infrared, untraviolet, and visible
10 components with selected polarizations. In addition, the
polarization converter may be used to produce other final
polarization states. The final polarization, for example,
could be left and right handed circular polarization
instead of s-polarization and p-polarization.

15 An alternative method for spectrally
distributing the light and converting the polarization of
the components may be accomplished by separating the light
spectrally before separating the light by polarized
components. The first step involves producing white light
20 that is typically randomly polarized and has at least two
spectral components. The light is separated spectrally
into a first component and a second component. The first
component is then separated into a first polarized
component having a first polarization and a second
25 polarized component having a second polarization. The
polarity of the second polarized component is changed to
the first polarization. Similarly, the second component
is separated into a third polarized component having a
first polarization and a fourth polarized component having
30 a second polarization. The polarization of the third
polarized component is changed to the second polarization.
This results in the first component having the first
polarization, and the second component having the second
polarization.

3.   Projection Display System Having a Spectrally
        Distributed Polarization Converter

The spectrally distributed polarization converters of the present invention may be combined with the projection display systems of the present invention. FIG. 19 illustrates a projection display system 400 which is identical to FIG. 7, except that the pre-filtering stack 113 has been replaced with the spectrally distributed polarization converter 230 shown in FIG. 17. Likewise, FIG. 20 illustrates a projection display system 410 which is identical to FIG. 8, except that the pre-filtering stack 113 has been replaced with a spectrally distributed polarization converter 230. In each of these projection display systems 400 and 410, substantially all of the light from the lamp 100 is transmitted through the spectrally distributed polarization converter 230 into the projection systems 83 and 124, respectively, resulting in a brighter projected image. Additional optics may be desired between the polarization converter 230 and the projection systems 83 or 124 to provide alignment, collimating, or other optical adjustments.

        FIG. 21 illustrates a projection display system that includes the spectrally divergent PBS array shown in FIGS. 18A and 18B together with the system of FIG. 8 with the cholesteric filter stack being removed.

        Thus, a projection display system for reflective light valves, and several variations thereof have been disclosed. Although a preferred embodiment of the invention, and several variations thereof, have been disclosed, it will be appreciated that further variations and modifications thereof may be made without departing from the scope of the invention as defined in the appended claims. It will also be understood that depending on the particular embodiment developed, one or more of the aforementioned advantages may be achieved. In addition, transmissive light values (modulators) may also be used in

combination with light having different polarities, if
desired.

  The terms and expressions which have been
employed in the foregoing specification are used therein
5 as terms of description and not of limitation, and there
is no intention, in the use of such terms and expressions,
of excluding equivalents of the features shown and
described or portions thereof, it being recognized that
the scope of the invention is defined and limited only by
10 the claims which follow.